Efficient Inversion in Underwater Acoustics with Analytic, Iterative and Sequential Bayesian Methods

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Award Number: N000141310077
Category of research: shallow water acoustics

LONG TERM GOALS

The long term goal of this project is to develop efficient inversion algorithms for successful geoacoustic parameter estimation, inversion for sound-speed in the water-column, and source localization, exploiting (fully or partially) the physics of the propagation medium. Algorithms are designed for inversion via the extraction of features of the acoustic field and optimization. The potential of analytic approaches is also investigated.

OBJECTIVES

- Achieve accurate and computationally efficient inversion for propagation medium parameters and source localization by designing estimation schemes that combine acoustic field and statistical modeling.
- Develop methods for passive localization and inversion of environmental parameters that select features of propagation that are essential to model for accurate inversion.
- Implement Bayesian filtering methods that provide dynamic and efficient solutions for the first two objectives.
- Develop analytic techniques for sediment sound speed estimation.

APPROACH

We extended a new sediment sound speed estimation scheme based on Stickler's inverse problem approach [1, 2] that the PI had developed. As we will show in the results section, we managed to estimate sediment sound speed and thickness in a synthetic waveguide using an analytic method, improving on previously obtained results with a similar but simpler approach.

Also, continuing efforts from previous years, we worked with Bayesian approaches applied to sound signals for the extraction of acoustic features using a combination of physics and statistical signal processing. We extended work on the development of a quasilinear model for source location, bathymetry, and water column sound speed profile estimation. We demonstrated that the method can be successful even under adverse noisy circumstances.

WORK COMPLETED

Sediment sound speed and sediment thickness were estimated using a new efficient analytic method. Despite low frequencies used for the inversion, high resolution was attained with parameters accurately extracted. With the help of a regularization method that we developed, the method resulted in successful sediment sound speed estimation even in noisy environments.

We extended work on the development of our quasilinear model for source location, bathymetry, and water column sound speed profile estimation. A main feature of the method is that it estimates EOF coefficients and provides their probability density functions. That allows us to include in the linearization process the complete sound speed profile, a task that had, to date, been difficult to tackle (previously, only shifts in sound speed profiles were considered in linearization). During the previous year, we extended the method so that it is effective even for low SNRs.

RESULTS

For completeness, Figure 1 shows results from previous work, where we demonstrate the effectiveness of our interpolant method in estimating sediment sound speed profiles. The figure illustrates the true sound speed profile and estimates using a simple Born approximation, a modified Born approximation, and our interpolant technique [3]. The interpolant approach provides closer profiles to the true one than other methods, with the improvement mostly evident at the interfaces between different sediments. This feature is the one that also allows accurate estimation of the sediment thickness.

The method was now applied to noisy data and was found to be successful after the implementation of a regularization approach for SNRs of 40 dB and higher. Figure 2 shows recent results for three SNRs and a frequency of 10 Hz for a simple step profile. Experimenting with more frequencies in order to study the effect of different sources on the quality of our results, we also performed the inversion at two more frequencies. Figure 3 shows sound speed profile estimates at 15 and 20 Hz for the same profile of Figure 2. As expected, comparing Figures 2(a), 3(a), and 3(b), we see that resolution increases with higher frequency (which, however, may present us with a complication because modes may be excited).

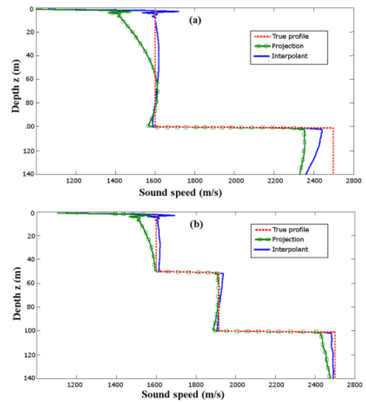

Figure 1: Performance of the analytic inversion method with interpolation in sediment sound speed profile estimation.

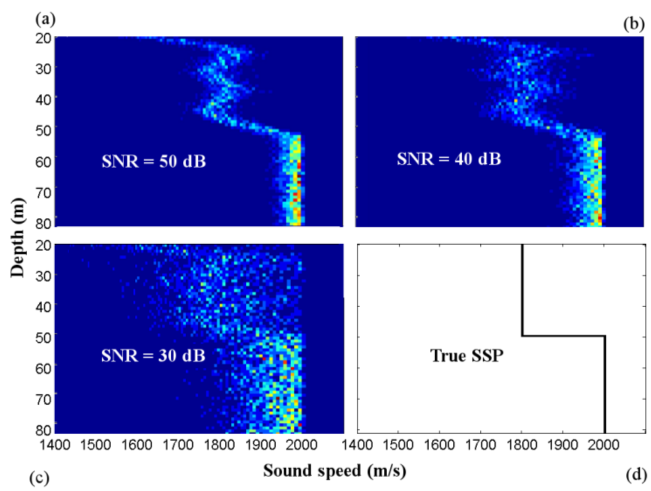

Figure 2: Performance of the analytic inversion method at three different noise levels for a step profile at a frequency of 10 Hz.

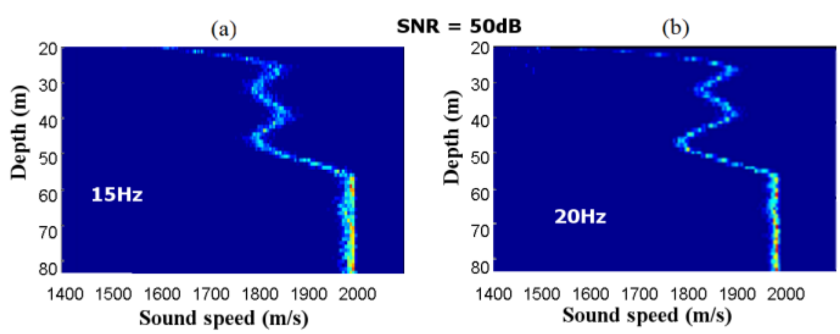

Figure 3: Performance of the analytic inversion method at two different frequencies for the profile of Figure 2.

Most direct methods have been tested with step profiles. In Figure 4 we show that the new method is effective even with a profile with a gradient.

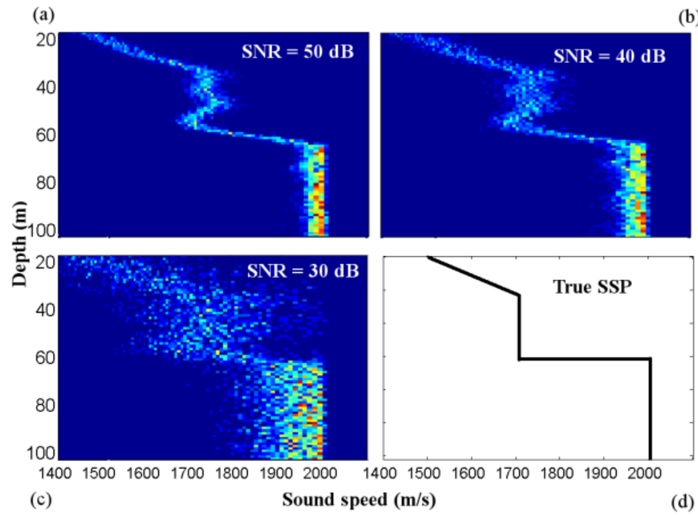

Figure 4: Performance of the analytic inversion method at three different noise levels for a profile with a gradient.

On the quasilinear method, we extended the approach for effective estimation under low SNRs. Figure 5 shows posterior probability density functions for source range, source depth, water column depth, and three EOF coefficients. Although the spread of the functions is significant, the Maximum a Posteriori estimates are very close to reference values of the parameters.

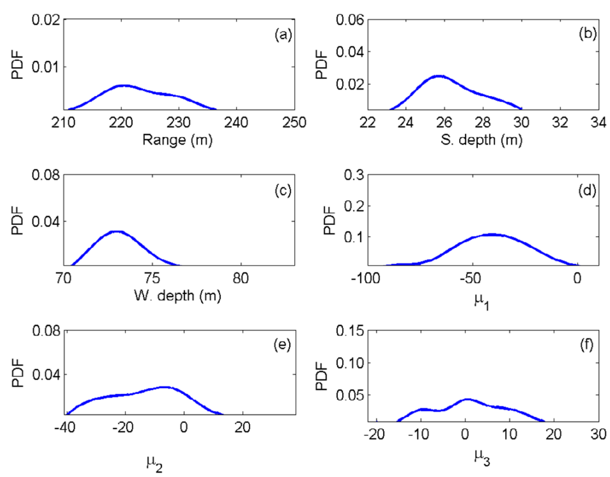

Figure 5: Probability density functions of (a) source range, (b) source depth, (c) water column depth, and (d), (e), (f) the first three EOF coefficients for a low SNR.

IMPACT

The development of the new inversion method has a significant impact on the problem of geoacoustic parameter estimation, because of its potential to estimate sound speed in sediments in an exact, fast,

analytic fashion. The method relies on limited prior information (sensitivity to assumptions is currently being further investigated).

Additionally, our inversion method with multipath arrival times and linearization is fast and accurate, allowing for effective inversion in real time. It also provides a straightforward tool for estimating the complete sound speed profile in the water column, a task that, to date, was a challenge with linearization methods and the formulation of the necessary partial derivatives in the Jacobian matrix.

RELATED PROJECTS

The PI is collaborating with Drs. Yardim and Gerstoft on passive fathometer processing in ocean acoustics. The PI is also collaborating with Dr. Leon Cohen on comparing numerical and analytical descriptions of dispersion in ocean environments.

REFERENCES

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PUBLICATIONS

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